

# **U.S. Army Research Institute of Environmental Medicine**

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## **ESTIMATED METABOLIC HEAT PRODUCTION OF HELICOPTER AIRCREW MEMBERS DURING OPERATIONS IN IRAQ AND AFGHANISTAN**

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**United States Army  
Medical Research & Materiel Command**

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**ESTIMATED METABOLIC HEAT PRODUCTION OF HELICOPTER AIRCREW  
MEMBERS DURING OPERATIONS IN IRAQ AND AFGHANISTAN**

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## EXECUTIVE SUMMARY

The degree of heat strain experienced by helicopter Aircrew varies with environmental condition, the physical demands of the mission, clothing and equipment worn, and individual characteristics such as age, height, weight, percent body fat, degree of heat acclimation, pharmaceutical use, and physical fitness. Heat strain, i.e., elevated skin and core temperatures, increases the risk of heat illness and injury, i.e., heat exhaustion and heat stroke. However, the level of heat strain in Aircrew members conducting in-theater operations is unknown.

Nevertheless, helicopter Aircrew members are at risk of heat illness. Aircrew members are often reserve Army Soldiers who are generally older, have a higher percent body fat, and are physically less well conditioned than younger active duty Soldiers. Aircrew members can spend more than eight hours per day performing strenuous intermittent work in hot operational environments; and summer time air temperatures in Afghanistan and Iraq can exceed 43.3°C (110°F). Aircrew members commonly wear or carry up to 30 kg of protective clothing and equipment while performing their work. Typical activities include dismounting from the aircraft and running to retrieve a casualty or to combat exercises such as defending the helicopter.

The duration and intensity of work performed by Aircrew members during their missions, and the associated rates of metabolic heat production, is unknown. The purpose of the present study was to estimate energy expenditure and metabolic heat production by Aircrew members during in-theater operations. These values will be used to estimate heat strain in Aircrew members under various conditions, and to develop Aircrew cooling systems that conform to aircraft power, weight, and volume constraints.

**Methods:** Male Aircrew members ( $n = 18$ , age:  $35 \pm 8$  yrs, wt:  $87 \pm 10$  kg, ht:  $178 \pm 7$  cm; mean  $\pm$  standard deviation) having in-theater operations experience served as test volunteers. Participants were Aircrew members on Blackhawk (UH-60) or Chinook (CH-47) helicopters. The type and length of time for each activity was estimated through focus group interviews. Energy expenditure and metabolic heat production were estimated by the factorial method using activity type, time performing that activity, body weight, and weight carried. Individual energy expenditures in kilocalories (kcal) were determined for each period of activity. Total training day energy expenditure was estimated from the various activities an individual performed. Metabolic heat was estimated using a mechanical efficiency of 20% for human movement and a standardized conversion to watts (W) ( $1 \text{ kcal/hr} = 1.163 \text{ W}$ ) as needed.

**Results:** Aircrew members expended approximately  $3400 \pm 1400$  kcal during their  $13.0 \pm 3.5$  hour in-theater mission. Estimated 24-hour daily energy expenditure



was ~5300 kcal. Average rate of metabolic heat production over the entire exercise was  $238 \pm 60$  W. Estimated peak metabolic heat production for activities lasting about one minute averaged  $935 \pm 425$  W and varied widely from 406 to 1750 W. Typically, sprinting short distances with 15 to 20 kg of equipment was the cause of these peak periods of heat production. There was large individual variability in the amount and pattern of metabolic heat produced.

**Conclusions:** The average metabolic heat produced over the work day was low because of extended periods of sitting in the helicopter. However, bursts of high intensity physical activities, such as repetitive sprinting while carrying equipment in hot environments, poses a risk of compromised job performance and thermal illness or injury for these Aircrew members.

## INTRODUCTION

Product Manager Air Warrior (PM AW) has a need for portable cooling systems that are effective but as small and light as possible. The system likely will be a cooling vest with a small battery pack similar to other cooling vests previously developed (26). The Capability Development Document (CDD) for Air Soldier System states the need for a heat stress solution (Attribute 33 with the minimum capability of sufficient cooling to be provided while in the helicopter (the CDD threshold) and the ideal to be sufficient cooling while in the helicopter and when dismounted (the CDD objective) (26). To guide work, Natick Soldier Research Development and Engineering Center (NSRDEC) developed a performance specification for a Lightweight Environmental Control System (LWECS), which will provide personal cooling capability to Aircrew personnel. This LWECS development is part of the Air Soldier Engineering & Manufacturing Development (EMD) program, which achieved its Milestone B decision on December 2011. There are two pending contracting actions as of April 2012 (Date of this Report) in the Natick Contracting Division to develop the LWECS. The goal of this research was to estimate physical activity patterns and metabolic heat production and the thermal strain on Aircrew members of the UH-60 (Blackhawk) and CH-47 (Chinook) helicopters. By having an estimate of the thermal strain imposed during actual missions, PM AW can better plan how to effectively design and incorporate cooling devices into the Aircrew ensemble and/or into the aircraft itself. Currently, the rear crews in these helicopters are tethered to stand alone cooling systems positioned in the helicopters.

Metabolic heat production can be estimated from total metabolic energy expenditures. Sawka and Wenger (21) report that depending on the type of exercise, between 70 and 100% of the metabolic energy produced will be released as heat and needs to be dissipated in order to maintain body heat balance. There are several ways of assessing energy expenditure and metabolic rates. Two of the more accurate ways of assessing energy expenditure are through doubly labeled water or indirect calorimetry (15). However, doubly labeled water requires measurement periods of days not hours (15). Indirect calorimetry typically requires wearing a mask and capturing the expired gases for real-time or post hoc analysis (15). These approaches are not feasible when trying to assess energy expenditure of crews during a daily combat mission in Iraq or Afghanistan. Therefore, the factorial method was chosen as the best method to assess energy expenditure of Aircrew members. It was not possible to have a data collector on-board a helicopter while these Aircrew members were executing their missions. Through a focus group procedure, a re-construction of the mission tasks was accomplished and then the factorial method of estimating energy expenditure was applied. The factorial method (15, 27), an accepted time-allocation method for estimating energy expenditure, involves recording the type of activity engaged in by the participant for a given increment in time (typically 15 min), and assigning a metabolic rate to that activity using values from published compendia of the amount of energy required to perform those physical activities (2, 3, 15). By summing all the activities, and using body weight and other weight worn or carried, a reasonable estimate of the average energy cost and metabolic heat produced of these Aircrew members during typical missions can be determined.

A number of studies have reported thermal strain levels associated with pilots or Aircrew members using different types of aircraft or in-flight simulators (11, 16, 17, 18, 19, 20, 22, 24). For example, Reardon et al. (19) examined the thermal strain associated with simulated flying in a Blackhawk helicopter. This was a controlled study within a flight simulator examining the thermal strain on pilots in two different ambient conditions, 21.1°C vs. 32.2°C WBGT (wet bulb globe temperature) while wearing two different clothing ensembles, MOPP0 (Mission-Oriented Protective Posture 0) and MOPP4. (MOPP 0 is the military Battle Dress Uniform (BDU) and MOPP4 is a higher level of protection with the chemical protective overgarment, hood, mask, boot covers, and gloves worn.) They found MOPP4 increases thermal strain significantly over MOPP0.

A recent study by Shender et al. (22) documented the environmental temperatures that Aircrew members were exposed to when flying missions in Central and Western Iraq in August of 2006. Cabin conditions peaked at 65.7 °C air temperature and 13.5% RH, while mean cabin conditions were 42.4 °C  $\pm$  5.4 °C and 9.8% RH  $\pm$  3.9% RH. Cockpit conditions peaked at 53.8°C and 21.1% RH and averaged 43.9  $\pm$  4.2 °C and 7.9  $\pm$  3.1 % RH. The microclimate within helicopters can be extreme, with elevated air temperatures, relative humidity, and solar load, with the greenhouse effect further exacerbating these environmental conditions if the windows are up (7). The clothing and individual equipment worn can be semi-encapsulating, again only making the problem of thermal strain experienced more likely. Regarding the impact these helicopter cockpits/cabin have on the crew's physiology, it was found that 27% of the variance in increased skin temperatures of pilots in Bell 206 and 212 helicopters was related significantly to increases in cockpit wet bulb temperatures (6).

There has been limited research looking at ways to cool or mitigate the thermal strain experienced by helicopter pilots. Katz et al. (11) reported that an Air Warrior Chemical Protective ensemble with microclimate cooling was effective in reducing the effects of heat strain in pilots and co-pilots at 21.1°C and 37.8°C air temperature while in a Blackhawk flight simulator. Another study showed that a microclimate cooling system worn next to the skin could alleviate some of the thermal burden experienced (10). Banta and Braun (4) showed that skin temperatures were lower when ice vests were worn during at-sea operations in Navy H-3 helicopters

While pilots have cooling systems they generally do not leave the helicopter during missions and their systems don't need to be portable. Aircrew members in the back of the cabin often dismount the aircraft. They need a cooling system that can be used when they become dismounted and at present they do not have one. This puts them at risk for experiencing heat strain. Furthermore, there are no published studies that document the thermal strain of Aircrew members participating in actual missions in Blackhawk or Chinook helicopters. Hence, it is unknown how much cooling they might need. This report provides estimates of energy expenditure and metabolic heat production of Aircrew members while performing in-theater missions in these helicopters.

This data may be used to help guide the development of cooling systems by PM-AW and NSRDEC. The more cooling that is needed the greater the power requirements and the larger the system, which increases the weight and bulk an Aircrew member must carry. Hence, obtaining reasonable estimates of metabolic heat production will help ensure that any cooling system developed will be optimized, i.e., not larger or heavier than needed to provide the necessary cooling to maintain an Aircrew member's health or performance.

## METHODS

Aircrew members who had participated in missions on Blackhawk or Chinook helicopters were studied. The Blackhawk helicopter is a twin-turbine helicopter that has four Aircrew members. The main cabin is open to the cockpit; enabling communication between the flight crew and the pilot. The cabin can accommodate up to 20 combat troops. This helicopter is often used as an air ambulance carrying up to four litter patients. The Chinook helicopter is a twin-engine medium transport helicopter with dual controls for two pilots. The main cabin accommodates up to 36 troops or 24 litters plus two attendants.

Volunteers were interviewed in focus groups (four to six participants per focus group) to determine the time course of the various activities they performed during a typical duty day during in-theater operations. Using this modified factorial method, energy expenditures were estimated. Detailed methodology regarding the factorial method of estimating energy expenditure and metabolic heat production is described below.

## VOLUNTEERS

Eighteen male volunteers were recruited from the Martindale Army Airfield, Texas ( $n = 10$ ) and Wheeler Army Airfield, Hawaii ( $n = 8$ ) training locations. Volunteers from Martindale were reserve Army Soldiers. Volunteers were briefed on the purpose, risks, and benefits of the study and gave their written informed consent prior to study participation. This study was approved by the Scientific and Human Use Review Committees at the U.S. Army Research Institute of Environmental Medicine.

Test volunteers flew in either Blackhawk ( $n = 14$ ) or Chinook ( $n = 4$ ) helicopters. All volunteers reported serving in Iraq and/or Afghanistan. Participants were experienced personnel (1 Command Sergeant Major (CSM), 2 Sergeants First Class (SFC), 4 Staff Sergeants (SSG), 6 Sergeants (SGT), 4 Specialists (SPC), and 1 Corporal (CPL)) and reported taking part in approximately 988 (range: 6 to 7000) training missions and 174 (range: 21 to 365) in-theater missions. Volunteers averaged  $35 \pm 8$  yrs (mean  $\pm$  standard deviation) (range: 23 to 48 yrs of age). On average, they spent  $67 \pm 50$  months (range: 11 to 168 months) at their present duty station and had  $14 \pm 8$  yrs (Range: 3 to 27 yrs) of military experience. They weighed  $87 \pm 10$  kg and were  $177 \pm 7$  cm tall. Differences in height and weight between helicopter crews were not significant, although the sample size for Chinook Aircrew members was very small

( $n = 4$ ). Self-reported 2-mile run times ( $15:49 \pm 1:43$  [minutes: seconds]) ( $n = 16$ ) were used to estimate  $\text{VO}_{2\text{ max}}$ .

## **METABOLIC COST CALCULATIONS**

A MET level was assigned to each physical activity by matching the activity to the closest equivalent activity in the Ainsworth et al. compendia of physical activities (2,3). Activities in the compendia are expressed in terms of MET levels of energy expenditure. A MET is defined as the ratio of metabolic work rate to a standard resting metabolic rate (15). Therefore, 1 MET = 1.0 kilocalorie (kcal) x body weight (kg) per hour. For example, for an 80 kg person, sitting in a chair for an hour expending 1 MET, would equate to 80 kcal energy expenditure for that hour. To calculate metabolic heat production, a mechanical efficiency of muscular work of 20% was assumed (21, 23). Therefore, metabolic heat production was 80% of total metabolic energy expenditure, while useful external work was 20% of total metabolic energy expenditure. Total energy expended was multiplied by 0.8 to represent that 80% of energy expended as heat. Metabolic heat production was converted to watts (W) of heat produced. The standard conversion equation of 1 kcal/hr equals 1.163 W was used. While mechanical efficiencies depending on the type of activity can vary, the 20% value was chosen as a reasonable fraction of the total to provide this rough estimate of metabolic heat production. Metabolic heat produced during the missions will be used to estimate how much cooling would be required for these Aircrew members.

Physical activities included walking, running, climbing up into and onto the helicopters, and sitting in the helicopter. While volunteers were sitting in the helicopter, they were often attending to a patient or manning a weapon. When volunteers were running they were often carrying equipment e.g., medical equipment needed to care for a fallen Soldier.

## **EXPERIMENTAL PROCEDURE FOR FOCUS GROUPS AND QUESTIONNAIRES**

Volunteers filled out a questionnaire at the start of the session. All information was obtained without the use of names, that is, only assigned volunteer identification numbers were used. Data were gathered anonymously to enhance candor. Questions included demographic questions (e.g., age, height, and weight) and job experience questions (e.g., time served as Aircrew members, job position, and rank). Volunteers then participated in focus groups to reconstruct the various physical activities engaged in during the missions. Focus group sessions were held with groups of four to six individuals. These sessions were video-taped. The use of focus groups allowed individuals to describe a typical day's activities in detail, including time spent doing each activity and what they were wearing and carrying. The moderator(s) followed recommended guidelines for focus groups such as not using jargon, making sure all volunteers contributed their ideas and/or experiences, did not allow one participant to dominate the conversation, and validated each idea as important (1). Topics besides re-constructing a day's activities proceeded from general to more specific as previously recommended (13). The videos from the focus group sessions were transcribed to a written narrative. From these narratives, data files were constructed that included

activity, time engaged in each activity, body weight, weight carried, and environment the activity took place in (e.g., sitting in an aircraft, standing or moving outside on a tarmac, etc.).

## DATA ANALYSIS

Data are presented as average W of heat produced over the course of the work day, and absolute peak W of heat produced during varying lengths of time. Descriptive statistics are presented as means  $\pm$  standard deviations (S.D.) and minimums (Min) and maximums (Max). One-way analyses of variance (ANOVAs) were used to identify significant differences between groups (e.g., by job position).

## RESULTS

The typical operational day had an average duration of about  $13.1 \pm 4.0$  hr. The average energy expended in physical activity among participants was  $3400 \pm 1400$  kcal during the in-theater operation. There were many different activities. The nature and length of time engaged in of these activities varied greatly across individuals. Some of the more typical activities included standing guard of the aircraft, loading the aircraft with equipment, climbing on the aircraft, sitting in the aircraft, running to patients, kneeling and treating a patient who was lying on the ground, and standing inside the aircraft while treating a patient. A rough estimate of total daily energy expenditure would be about 5300 kcal calculated by adding the estimated total energy expended during the mission to the estimated resting energy expenditure (~ 1900 kcal). Resting energy expenditure was calculated as 1 MET multiplied by body weight and number of hours of non-active energy expenditure including sleeping (0.9 MET). For these calculations, the amount of sleep the participants' self-reported for the day before the mission was used ( $7.2 \pm 1.1$  hr).

Estimated  $\text{VO}_2$  max was  $45.8 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  based on the previously established relationship between two mile run for time and body weight [ $\text{VO}_2 \text{ max} = -110.9 - (2.79 \times \text{Two Mile Run Time in Min}) - (0.25 \times \text{Body Weight in kg})$ ] (14).

## METABOLIC RATES

Metabolic heat production, unlike energy expenditure, cannot be summed because W are associated with time. Therefore, specific time periods of interest need to be established. Four time periods were used to calculate 1) average heat production for the entire operational time period, 2) peak metabolic heat production where the duration of activity was 30 minutes or greater, 3) peak metabolic heat production where the duration of the activity was 15 minutes or greater, and 4) peak metabolic heat production. Table 1 is a summary of metabolic heat produced categorized by the type of aircraft the Aircrew member was assigned to. A significant difference ( $p = 0.03$ ) in

average heat production was evident between aircraft, with Chinook crews generating slightly more heat for an average work day than Blackhawk crews ( $290 \pm 10$  W vs.  $220 \pm 60$  W respectively). However, part of this difference may have been due to the Blackhawk Aircrew members' longer work day 13.3 hr (Blackhawk crews) compared to 12.4 hr (Chinook crews). Blackhawk Aircrew members produced significantly more heat ( $p = 0.004$ ) when the maximum heat production for a time period of 30 min or more were examined ( $420 \pm 300$  W vs.  $230 \pm 60$  W). The time factor for the peaks values is not an average but rather the length of time that peak W output was sustained. For the shorter time periods of peak heat production lasting 15 min or longer, or peak heat production regardless of time sustained, no significant differences existed between type of helicopter assigned.

In the present study, most Aircrew members assigned to the Blackhawk helicopters were medical personnel. They would often be required to dismount the helicopter and run to a patient lying on the ground up to 150 m away. The total load weight used to calculate energy expenditure consisted of the medical equipment (weighing between 15 to 20 kg) they carried, the weight of the equipment they were wearing, and their body weight. Aircrew members in this sample averaged 87.2 kg in body weight which is substantially more than the average Soldier (~80 kg). Added weight (whether body weight or equipment weight) results in a greater energy cost and associated heat production for a given type of physical activity.

Metabolic heat production was also examined based on the participants' job position on the aircraft (Table 2). No significant differences between job positions existed, most likely because of the small sample size and lack of power to detect significant differences. For example, the mean metabolic heat produced for the peak of 30 min or more for Crew Chiefs was over 500 W ( $n = 7$ ), while the mean metabolic heat produced by Door Gunners or Flight Engineers were under 300 W. However, there were only two Door Gunners and three Flight Engineers, making it difficult to detect a statistically significant difference. Plots of the volunteers' estimated metabolic heat production over time are provided in Appendix A. These charts show large differences in activity patterns over time for each individual. Additionally, there are large differences among individuals in the patterns of metabolic heat production. However, no volunteer reported experiencing a heat illness or injury event during their military career including these operations.

**Table 1.** Average estimated rates of metabolic heat production during the work day, and peak rates of metabolic heat production, for all volunteers by assigned aircraft type (Blackhawk and Chinook).

Aircraft Type	N	Work Day Average			Peak ≥ 30 Minutes			Peak ≥ 15 Minutes			Peak		
Heat Produced (W)		± S.D.	Min	Max	± S.D.	Min	Max	± S.D.	Min	Max	± S.D.	Min	Max
Time (h:min)													
Blackhawk (UH-60)													
Heat Produced (W)	14	220 ± 60 <sup>a</sup>	120	350	420 ± 300 <sup>b</sup>	115	1020	540 ± 290	150	1020	1000 ± 450	410	1750
Total Time (h:min)		13:06 ± 3:59	3:25	16:52	1:03 ± 0:49	0:30	2:30	0:21 ± 0:07	0:15	0:40	0:07 ± 0:10	0:01	0:30
Chinook (Ch-47)													
Heat Produced (W)	4	290 ± 10 <sup>a</sup>	280	300	230 ± 60 <sup>b</sup>	150	280	480 ± 20	460	500	680 ± 30	645	720
Total Time (h:min)		12:27 ± 1:11	10:59	13:37	2:00 ± 0:35	1:30	2:30	0:20 ± 0:00	0:20	0:20	0:10 ± 0:00	0:10	0:10
Both Aircraft Types													
Heat Produced (W)	18	240 ± 60	120	350	380 ± 280	115	1020	520 ± 250	150	1020	940 ± 425	410	1750
Total Time (h:min)		13:06 ± 3:59	3:25	16:52	1:03 ± 0:49	0:30	2:30	0:21 ± 0:06	0:15	0:40	0:08 ± 0:09	0:01	0:30

\*W values are rounded to nearest 10 W.

<sup>a</sup> Blackhawk Work Day Average Values significantly less than Chinook Work Day Averages ( $p = 0.03$ ).

<sup>b</sup> Blackhawk Peak >30 Min Values significantly greater than Chinook Peak >30 Min Values ( $p = 0.004$ )



**Table 2.** Estimated average rates of metabolic heat production during the work day, and peak rates of metabolic heat production by job position.

Job Position	N	Work Day Average			Peak ≥ 30 Minutes			Peak ≥ 15 Minutes			Peak		
Heat Produced (W) Time (h:min)		± S.D.	Min	Max	± S.D.	Min	Max	± S.D.	Min	Max	± S.D.	Min	Max
Standardization													
Instructor													
Heat Produced (W)	1	200	200	200	450	450	450	740	740	740	1300	1300	1300
Total Time (h:min)		16:47	16:47	16:47	0:30	0:30	0:30	0:15	0:15	0:15	0:01	0:01	0:01
Crew Chief													
Heat Produced (W)	7	240 ± 80	150	350	510 ± 350	170	1020	630 ± 270	240	1020	1040 ± 31	400	1750
Total Time (h:min)		13:59 ± 3:39	6:18	16:45	1:16 ± 1:02	0:30	3:00	0:20 ± 0:05	0:15	0:30	11:07 ± 12.8	0:01	0:30
Flight Medic													
Heat Produced (W)	5	220 ± 40	150	240	330 ± 300	115	800	390 ± 300	150	800	1020 ± 460	660	1600
Total Time (h:min)		11:17 ± 6:05	3:25	16:52	0:35 ± 0:07	0:30	0:45	0:24 ± 0:10	0:15	0:40	0:05 ± 0:03	0:02	0:10
Door Gunner													
Heat Produced (W)	2	210 ± 30	190	235	270 ± 40	250	300	470 ± 70	420	520	550 ± 80	490	600
Total Time (h:min)		14:01 ± 3:59	14:00	14:04	0:32 ± 0:00	0:32	0:32	0:20 ± 0:00	0:20	0:20	0:01 ± 0:00	0:01	0:01
Flight Engineer													
Heat Produced (W)	3	300 ± 10	280	300	220 ± 65	150	280	480 ± 30	450	500	680 ± 40	650	720
Total Time (h:min)		13:11 ± 1:20	10:59	13:37	1:50 ± 0:35	1:30	2:30	0:20 ± 0:00	0:20	0:20	0:10 ± 0:00	0:10	0:10

\*W values are rounded to nearest 10 W.

## DISCUSSION AND CONCLUSIONS

Aircrew members experience heat stress from various environmental contributors including ambient temperature, relative humidity, and solar radiation inside and outside the helicopter. Metal surfaces of the helicopter get extremely hot from the engine and solar radiation adding thermal radiant heat as another source of heat to the thermal burden of Aircrew members. Metabolic heat produced by the body from physical activity also needs to be accounted for. Estimated heat production of Aircrew members is useful to apply to thermal-regulatory models for further understanding of individual physiology. Thermal-regulatory models using environmental factors (i.e., air temperature, relative humidity, solar radiation and wind speed), individual characteristics (e.g., hydration state, level of heat acclimation, body composition, anthropometry, etc.) and metabolic heat production as inputs, estimate individual physiology including core temperature, skin temperature, sweat rates, and thermal sensation. The predicted physiology and estimated heat production values may be used to guide the development of microclimate cooling systems for Aircrew members to mitigate the thermal burden they experience.

Metabolic heat production of Aircrew members was variable (see the large standard deviations associated with the various periods of peak activities in the tables). The primary source of heat production by these Aircrew members occurred when they were not in the helicopter (about 55 to 60% of their work day). Bursts of physical activity of less than 10 minutes duration may not pose a significant problem with regard to the thermal strain experienced by these Aircrew members. However, repeated bouts of exercise over the course of the day, particularly with elevated temperatures as in Iraq or Afghanistan in the summer, could increase the risk of thermal illness. No Aircrew member on this study ever self-reported a thermal injury. However, increases in thermal strain can impact mental and physical performance prior to the onset of heat illness or heat injury. Task performance requiring attention to detail or concentration can suffer significantly (12). Medical decisions and first aid procedures are often required during transport of a patient from a battle site to a field hospital. Reaction times and decision times are significantly longer when the body is thermally strained. Vigilance decreases somewhat after 30 minutes of heat stress but notably after two hours (5). While heat illnesses were not evident, critical life-saving decisions could be compromised due to the thermal strain experienced by these Aircrew members.

Aircrew members assigned to Blackhawk helicopters had significantly greater peak heat production than those assigned to Chinook helicopters. Chinook Aircrew members' average metabolic heat production was slightly higher than Blackhawk crews. These findings are not contradictory. While Blackhawk Aircrew members had higher peak heat generated they also had longer work days than the Chinook Aircrews. The additional time was usually spent in low energy expenditure activities such as standing guard of the helicopter or sitting while flying, resulting in a lower overall average amount of metabolic heat produced over the whole day. Regarding peak heat differences, there are two explanations. First, while Chinook helicopters carry heavier loads, and there were brief periods of time when Aircrew members had to assist in pushing or pulling these loads into the helicopter, most of the load is maneuvered mechanically. These

Aircrew members once they boarded the aircraft, tended to remain on the aircraft for longer periods of time, with less dismounting and running on the ground compared to Blackhawk Aircrew members. A secondary minor reason was that average body weight of the Blackhawk sample was 88 kg compared to an average body weight of 86 kg for the Chinook sample. Body weight is a contributing factor to the amount of energy expended for a given activity. The impact of body weight is greater with higher energy expenditure activities such as running.

Total daily energy expenditure was estimated to be approximately 5300 kcal, similar to other groups of Warfighters (25). The extended workday, heavier than average Soldier body weight, and carrying of equipment during walking, running, and climbing are the most reasonable explanations for this relatively high energy expenditure. However, total daily energy expenditure may have been over-estimated. The focus group factorial method of activity recall used was the same procedure used successfully with Border Patrol and Tactical Law Enforcement personnel (8, 9). However, those studies had volunteers recalling a previous day's activities. In contrast, this study had volunteers recalling a day's activities that were a few weeks to several months prior to the interview. In addition, during the Border Patrol study (9), amount and types of movements were verified using global positioning systems (GPS). During the Tactical Law Enforcement Study, a data collector was allowed to observe, time, and record the general types of activities performed (8). The logistical complexity of assessing Aircrew members in-theater while flying in helicopters did not allow the instrumentation of volunteers with any type of monitoring units nor was it possible to have activities observed and recorded by a trained data collector. The procedure used on this study likely resulted in an increase in measurement error. Previous research has shown that volunteers tend to overestimate both the time and intensity of activities they are recalling (15). However, the weight of the volunteers, weight of equipment, and the length of time spent running to a patient on the ground approximately 150 meters distance from the helicopter is likely to be reported accurately. While overall total daily energy expenditure estimates may be greater than actual measurements, the peak metabolic heat generated estimates in this study are likely to be accurate.

A major limitation of this study is the relatively small sample size ( $n = 14$  Blackhawk personnel,  $n = 4$  Chinook personnel), so caution in generalizing these results should be exercised especially with regard to the Chinook Aircrew metabolic heat production. No differences between job classifications was evident, but lack of significance is mostly attributable to the small sample ( $n = 1$  to 7) of Aircrew members per job classification. For studies of assessing metabolic costs of military personnel, more adequate sample sizes of 14 to 20 volunteers should be obtained (extraordinary attempts were made to obtain the necessary sample size on this study) and interviews should be conducted closer in proximity to the day of the mission. The use of physiological monitoring systems should also be considered for understanding the thermal strain of individual Aircrew members.

In conclusion, this study provided estimated rates of work and metabolic heat production by Blackhawk and Chinook Aircrew members. However, work rates and patterns of activities varied widely. At times, because of the activity, such as sprinting to

an injured Warfighter on the battlefield while carrying medical equipment, the metabolic heat generated can be quite high. If these activities were repeated over the course of a long duty day with little body cooling, the resulting increase in thermal strain could lead to compromised cognitive and physical performance and/or thermal illness or injury. These results provide a piece of key information in helping guide the development of cooling systems to allow Aircrew members to remain safe and perform their mission effectively.

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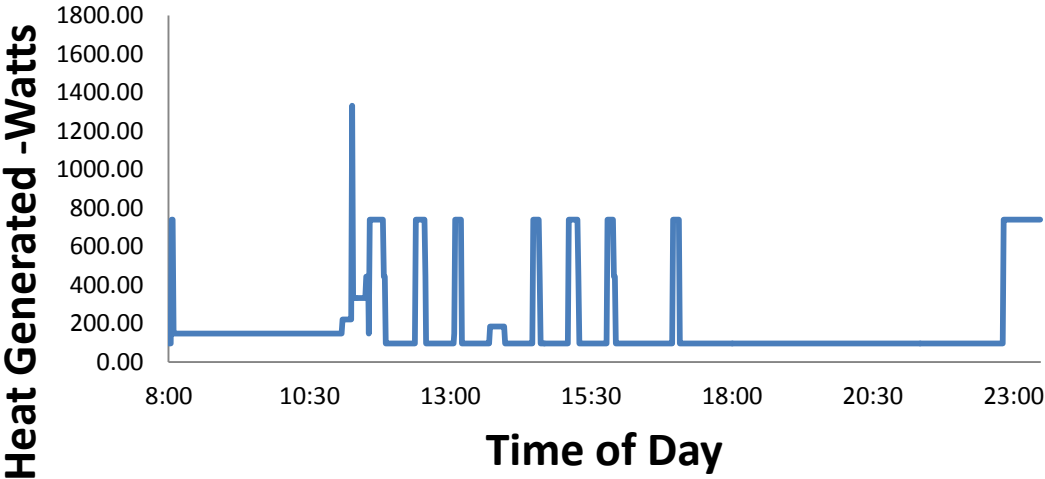
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## **APPENDIX A**

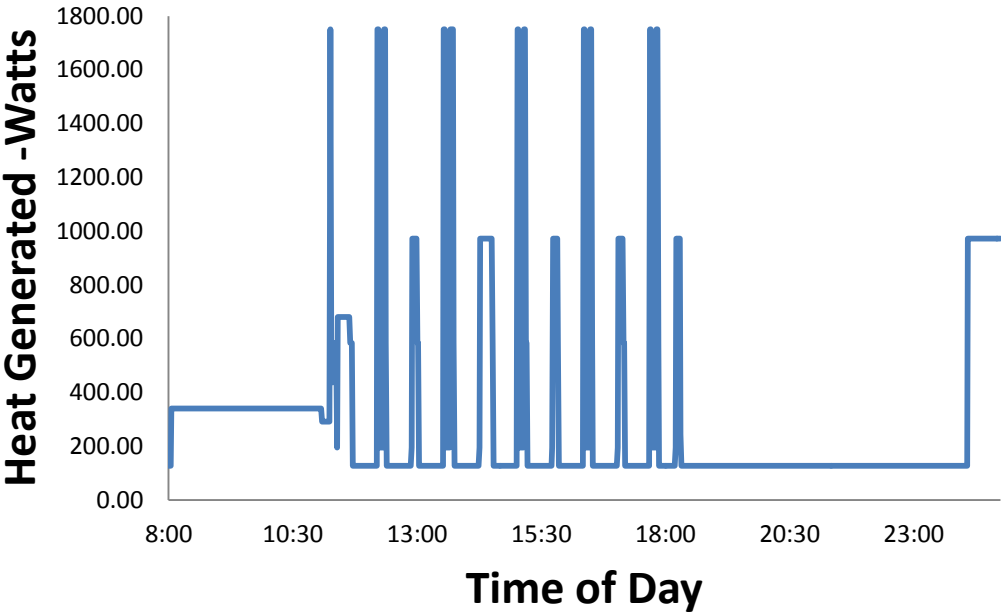
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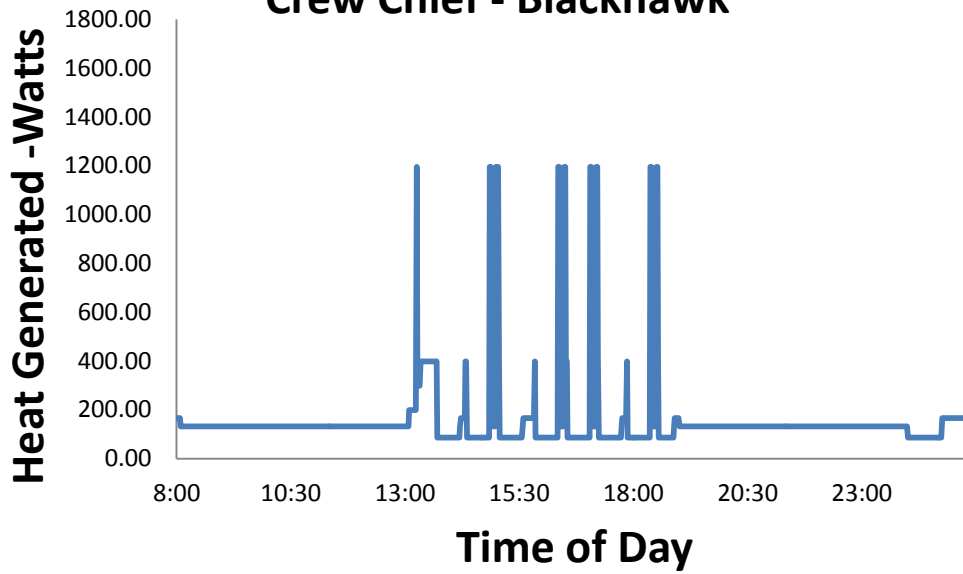
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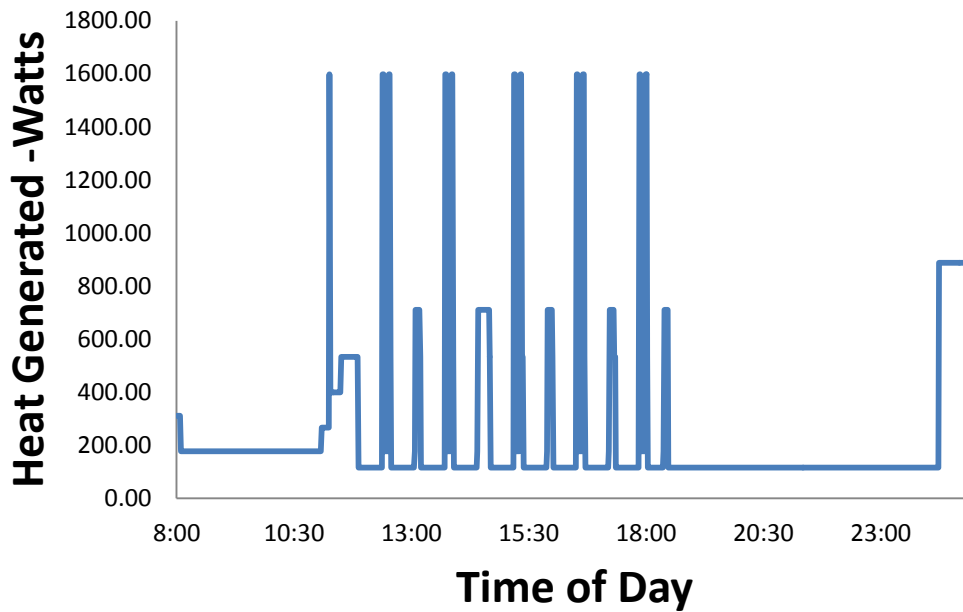
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**Crew Chief - Blackhawk**



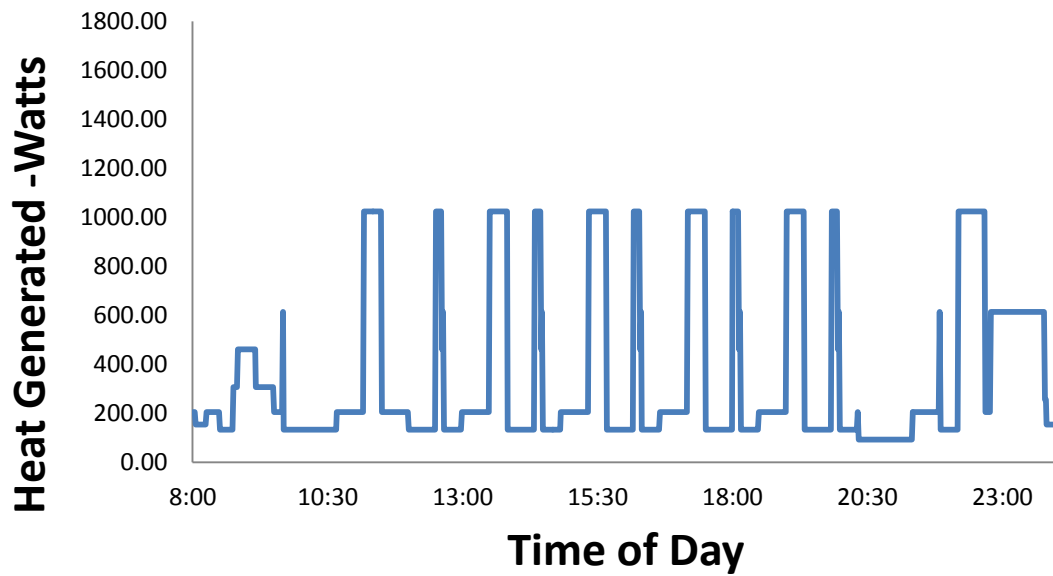
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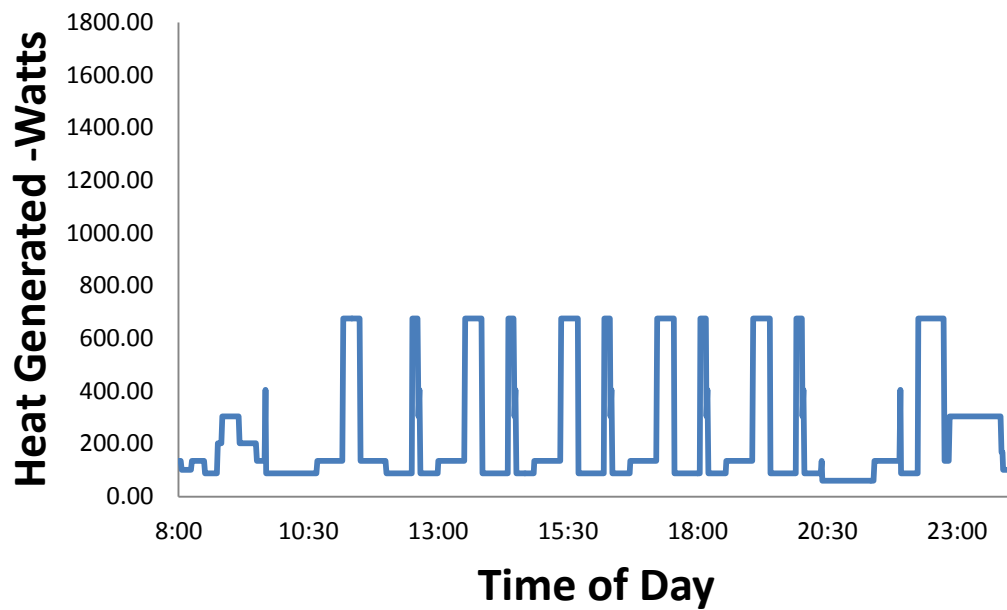
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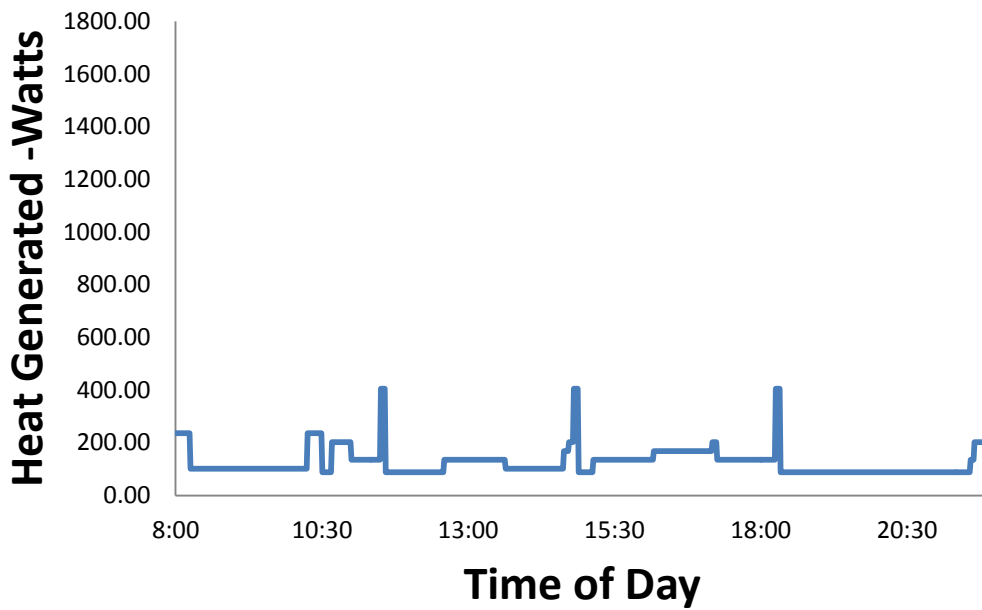
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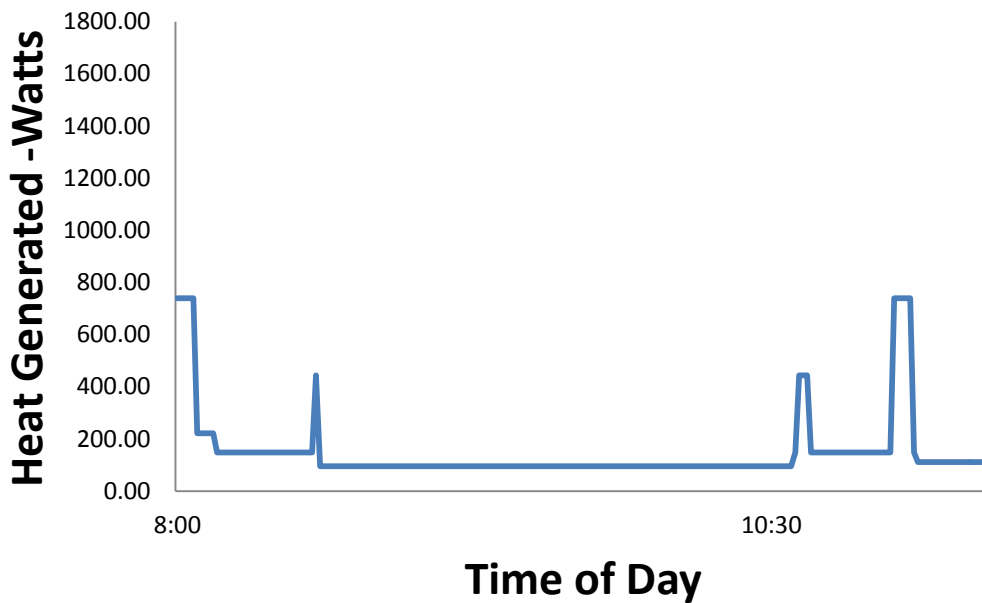
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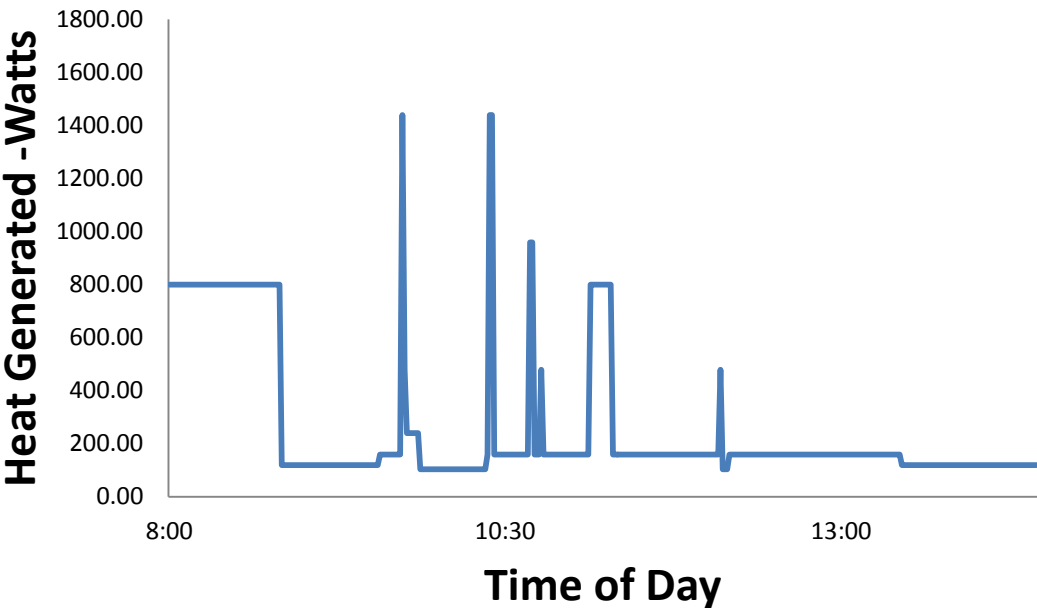
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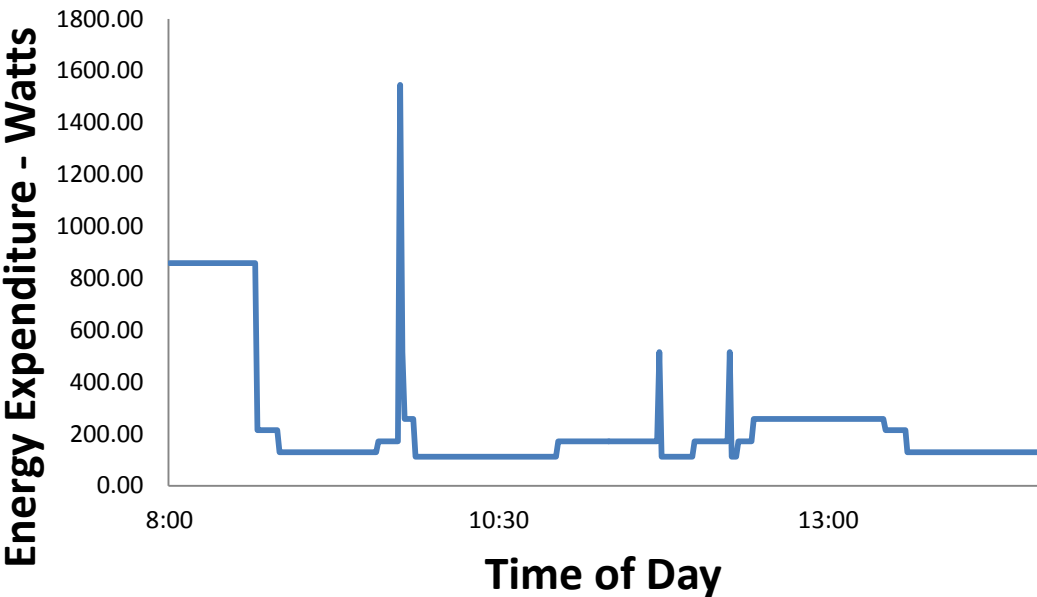
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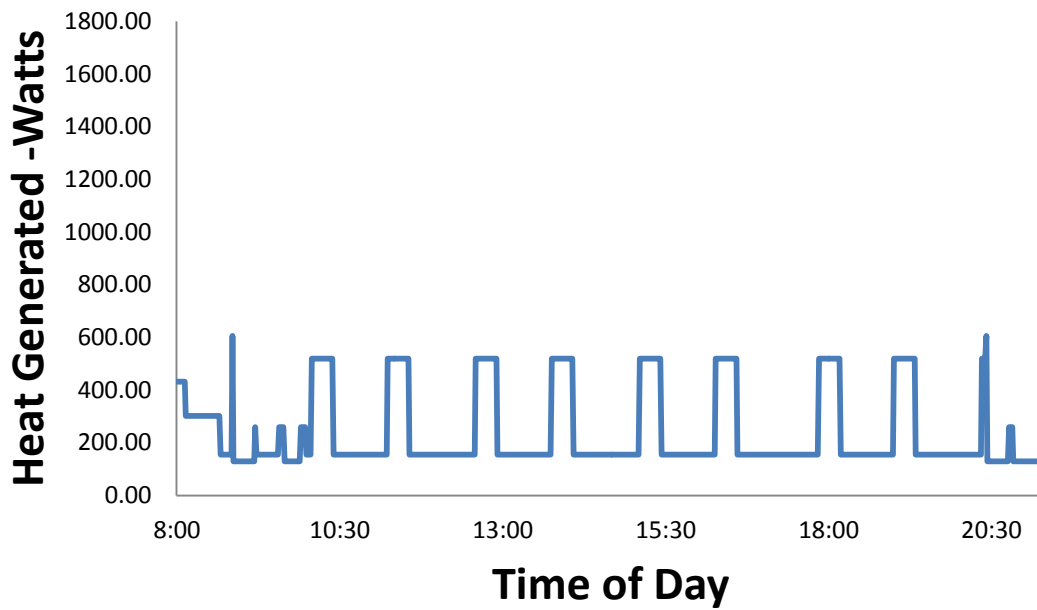
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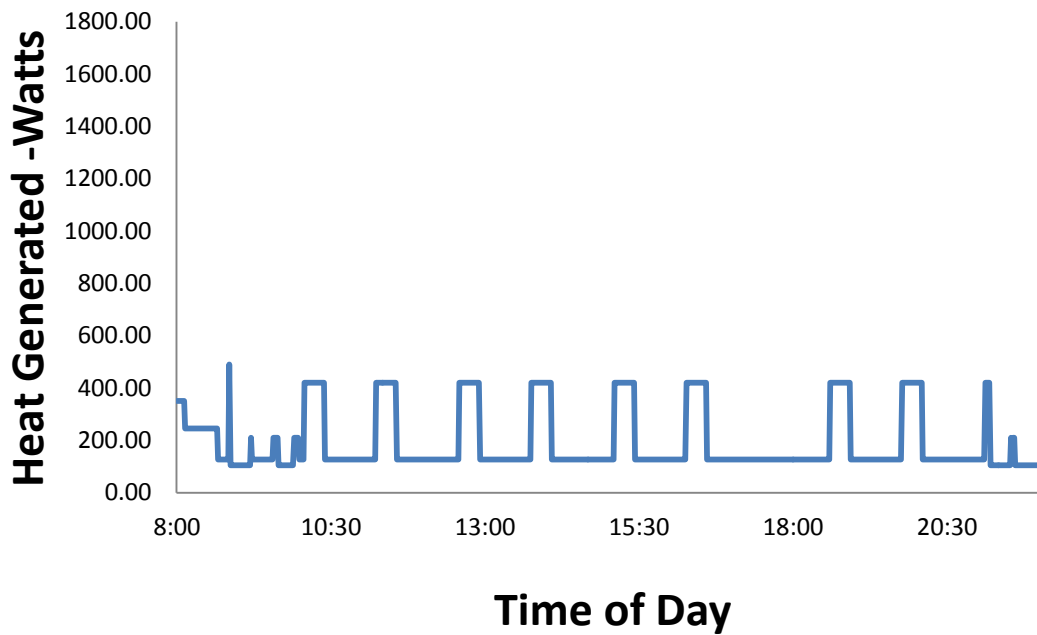
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**Crew Chief - Blackhawk**



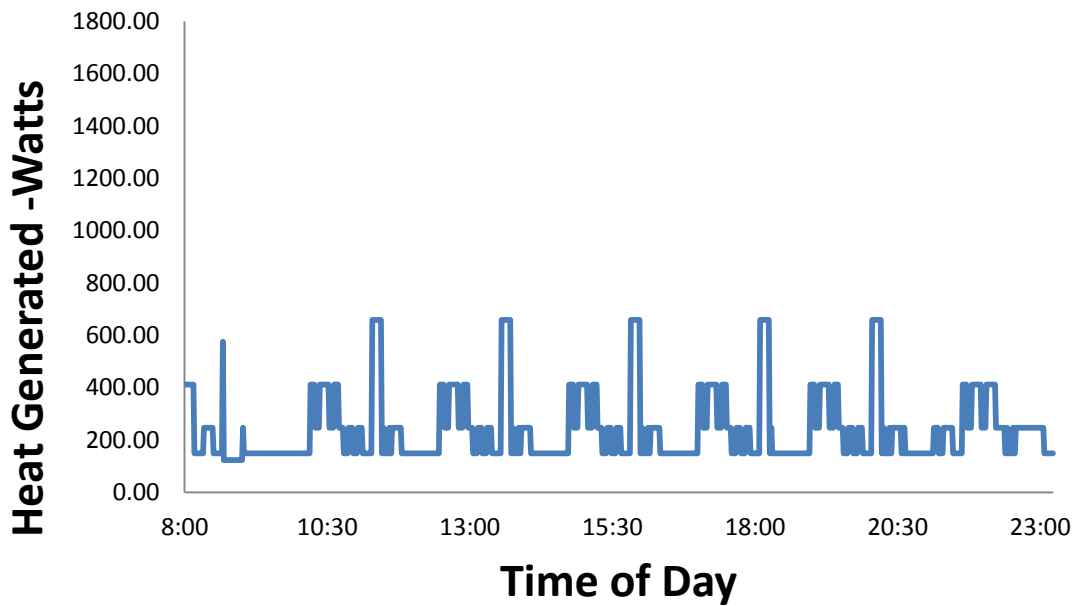
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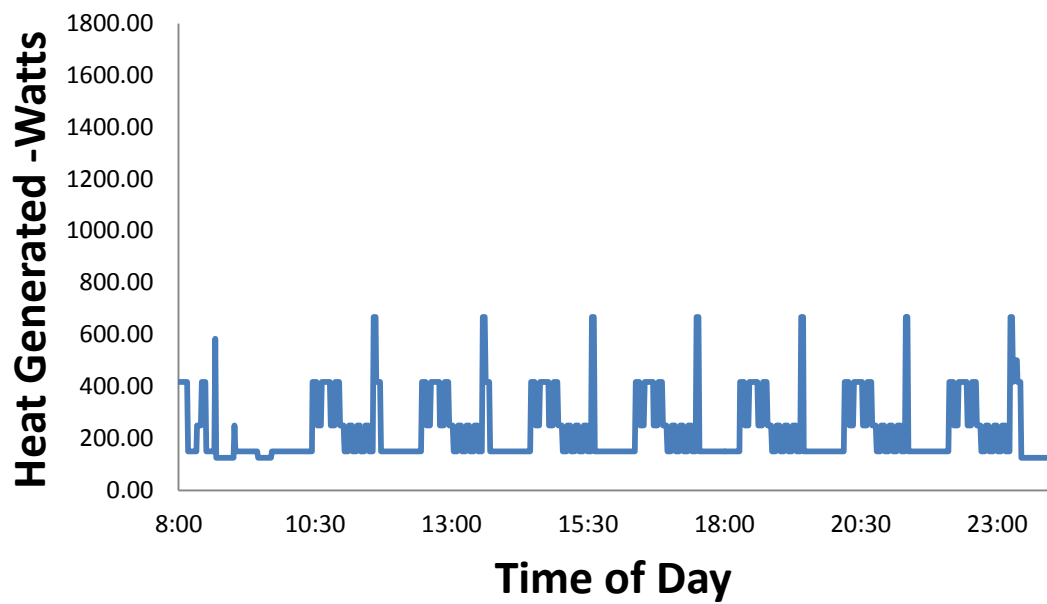
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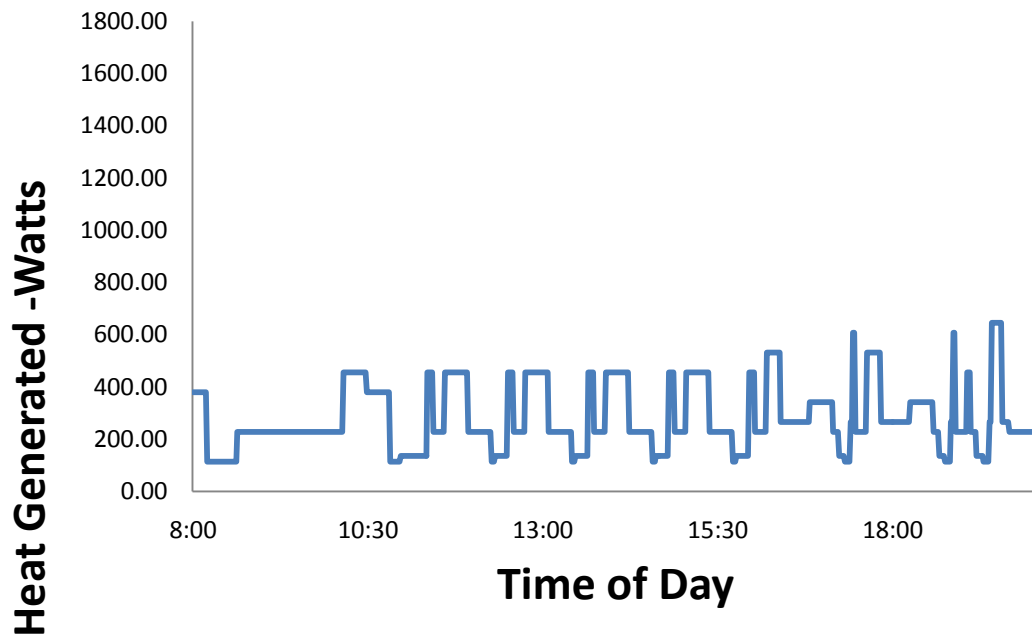
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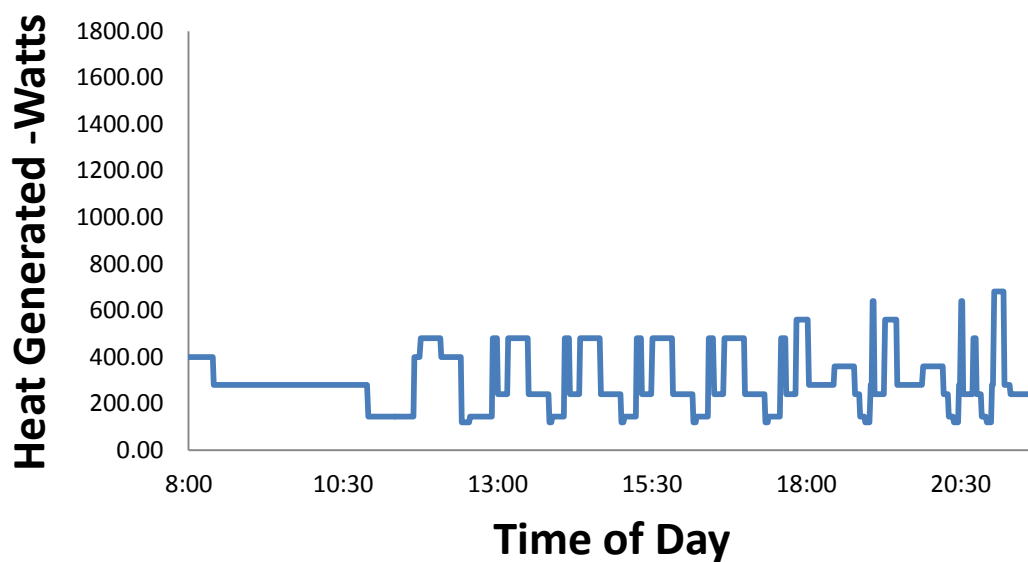
**Subject 104**  
**Flight Medic - Blackhawk**



**Subject 105**  
**Flight Engineer - Chinook**

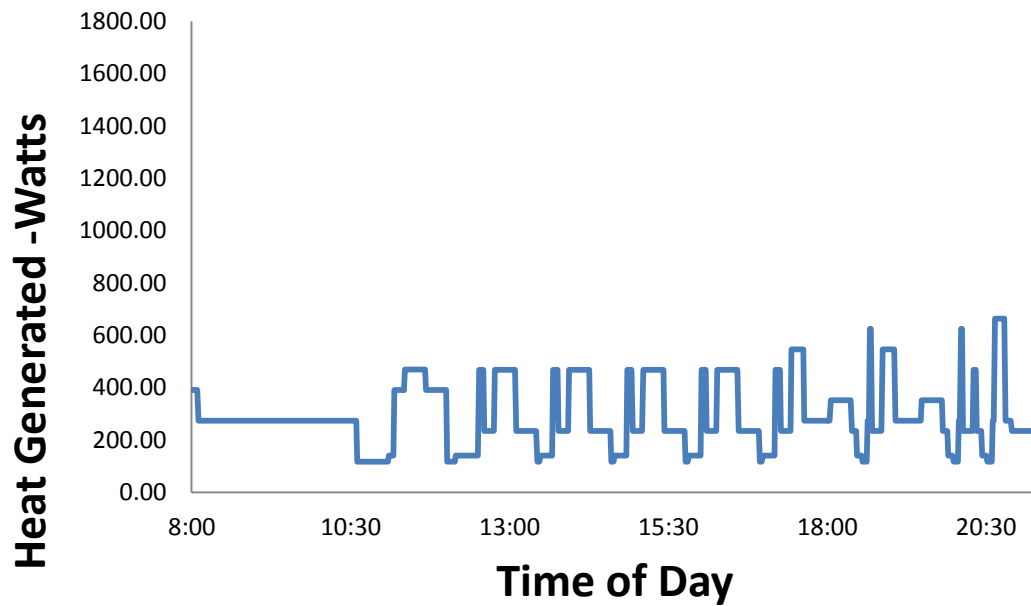


**Subject 106**  
**Flight Engineer - Chinook**





**Subject 107**  
**Crew Chief - Chinook**



**Subject 108**  
**Flight Engineer - Chinook**

